



DISSERTATION

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*ACTIVATION MEASUREMENTS
OF CAPTURE CROSS SECTIONS
FOR 14-15 MeV NEUTRONS*

Göran Magnusson

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FAST NEUTRON CAPTURE

The mechanism of the neutron capture process can be described by three different reaction models: the statistical model, the direct model and the semi-direct model. Below about 5 MeV neutron energy, the statistical model very well describes the results of capture cross section measurements. For energies above 5 MeV the experimental (n, γ) cross-section data are several orders of magnitude larger than the calculated values obtained on the basis of this model ¹⁾. To explain this discrepancy a direct capture process was suggested. The incident nucleon is captured into an empty bound single-particle orbit and the excess energy is emitted. This model gave about one order of magnitude too small cross-section values. At this point a semi-direct capture process was proposed by several authors ²⁻⁴⁾. They assumed the reaction to go through an intermediate state in which the captured neutron is in a single particle bound state of the product nucleus and the nucleus is excited to its giant-dipole state. With this model, theoretical values are obtained which agree with the experimental results within a factor of ten.

Two different methods are used in measuring the cross section for the radiative capture of fast neutrons: activation measurements and measurements of the spectra of prompt γ -rays.

The cross section, σ_{act} , obtained from the activation measurements covers the deexcitation through the γ -emission of the compound system via bound and unbound states of the final nucleus. The spectrum of prompt γ -rays provides a capture cross section to bound states only. The notation σ_{int} is used for these cross sections.

The results of σ_{int} at 14 - 15 MeV indicate that the cross section increases slowly with mass number up to about $A = 50$ and becomes nearly constant around 1 mb for heavier nuclei. This dependence is illustrated in Fig. 1. The activation cross sections, σ_{act} , differ markedly from the results

obtained by integration of γ -ray spectra for nuclei far from the closed neutron shells.

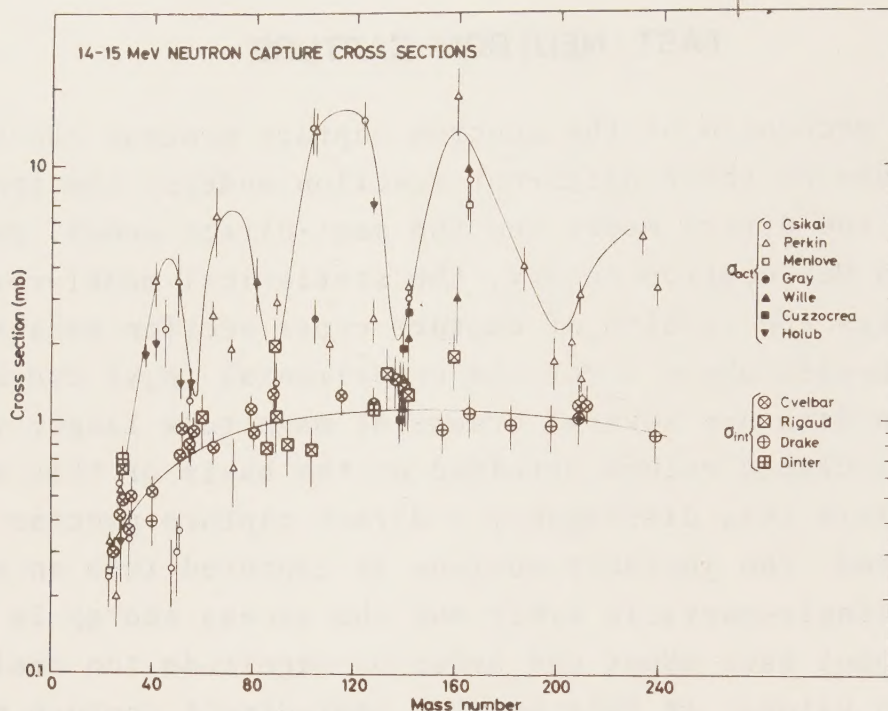


Fig.1 The neutron capture cross section at 14 to 15 MeV as a function of mass number taken from Ref. 5. The results obtained both with the activation method (σ_{act}) and with the spectrum method (σ_{int}) are included.

The differences in the experimental data could be qualitatively explained if one supposes that activation measurements are highly influenced by a contamination of low-energy neutrons. The neutron radiative capture cross section of a deformed nucleus increases very rapidly with the decrease of neutron energy, and therefor even a very small fraction of low-energy neutrons, can considerably alter the results of activation measurements. For magic or near-magic nuclei the influence of these secondary neutrons should be negligible, because the capture cross section in the low-energy region is about one or two orders of magnitude lower for such nuclei compared with the cross section for deformed nuclei.

The discrepancies in the experimental data, as well as the difficulty to give a theoretical explanation of the sensiti-

vity of earlier activation data to shell structure, have been the starting point for more accurate activation measurements.

14-15 MeV NEUTRON CAPTURE

The present dissertation is based on the following publications:

	Page
I K Ponnert, G Magnusson and I Bergqvist, MULTIPLE REACTION CORRECTION TO 15 MeV NEUTRON CAPTURE CROSS SECTION IN ^{115}In , Physica Scripta <u>10</u> , 35 (1974)	13
II G Magnusson and I Bergqvist, 14.7-MeV NEUTRON CAPTURE CROSS-SECTION MEASUREMENTS WITH IMPROVED ACTIVATION TECHNIQUE, Nuclear Technology <u>34</u> , 114 (1977)	21
III G Magnusson, P Andersson and I Bergqvist, 14.7-MeV NEUTRON CAPTURE CROSS-SECTION MEASUREMENTS WITH ACTIVATION TECHNIQUE, Nuclear Physics Report LUNFD6/(NFFR-3032)/1-22/1979	29
IV P Andersson, S Lundberg and G Magnusson, ABSOLUTE MEASUREMENTS OF SOME NEUTRON ACTIVATION CROSS SECTIONS IN ^{27}Al , ^{115}In AND ^{197}Au AT 14.9 MeV Nuclear Physics Report LUNFD6/(NFFR-3021)/1-22/1978	53
V G Magnusson and P Andersson, NENINA - A COMPUTER CODE FOR THE CALCULATION OF ENERGY DISTRIBUTIONS OF NEUTRONS INCIDENT ON A CIRCULAR DISC, Nuclear Physics Report LUNFD6/(NFFR-3030)/1-37/1979	75
VI G Magnusson, NUMERICAL ESTIMATES OF MULTIPLE REACTION CORRECTIONS IN NEUTRON CROSS-SECTION MEASUREMENTS, Nuclear Physics Report LUNFD6/(NFFR-3031)/1-20/1979 ...	113

The purpose of this dissertation has been to study the effects of secondary low-energy neutrons in neutron capture

cross-section measurements. An investigation was made to study the sources of these neutrons and based on this the experimental technique was improved. The essential feature of this new technique was to perform the neutron irradiation of the sample in a thin walled vacuum chamber made of aluminium. The method has been applied to 14.7 MeV neutron capture cross-section measurements for some different nuclei.

The activation technique was used to determine the capture cross sections. The method is simple:

a sample material is irradiated with neutrons. Thereafter the induced activity is measured. For the components of interest the absolute number of disintegrations is calculated. If the duration of the irradiation and the number of impinging neutrons are known, the cross section can be obtained.

The activation cross sections were determined relative to the cross section of the $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ reaction. In a separate experiment (paper IV) the cross section for this reaction has been measured by utilizing a neutron-proton telescope.

The neutrons were obtained from the $\text{T}(\text{d},\text{n})^4\text{He}$ reaction and the deuterons were accelerated by a Van de Graaff accelerator. Since the energy of the produced neutron depends on the emission angle, different parts of the sample are irradiated with neutrons of different energies. The energy spread and the mean energy of the neutrons hitting the sample were calculated by means of a computer code NENINA, described in paper V.

Secondary low-energy neutrons are produced by the following sources:

- a. thermal and epithermal neutrons scattered from the walls,
- b. neutrons produced by $(n,2n)$, (n,n') and (n,np) reactions in the tritium target backing, in the sample itself and in surrounding material,
- c. neutrons from the $\text{D}(\text{d},\text{n})^3\text{He}$ reaction because of deuterium build-up on the target.

In the arrangement described in paper I, the tritium targets were deposited onto 0.28-mm copper backing, barely thick enough to withstand the atmospheric pressure. The investigation of copper backing of different thicknesses indicated a rather strong dependence of the activation yield. The yields are in the papers given as apparent cross sections. Backings of larger thicknesses have probably been used in some previous capture activation measurements.

Several sets of experiments were performed to study the influence of the distance between the sample and the neutron source. The results showed a strong distance dependence on the apparent activation cross section. This can be understood in terms of capture of low-energy secondary neutrons produced in material surrounding the target and the sample.

The influence of secondary neutrons produced in the sample itself can be studied by observing the dependence of the sample thickness and diameter on the apparent cross section. Linear dependences were observed on either of these parameters.

In the following investigation (paper II) a new experimental set-up was constructed. A vacuum chamber was made of aluminium and with this arrangement the amount of material in the immediate vicinity of the neutron target and the sample could be kept small. The tritium targets were deposited onto 0.02-mm thick aluminium backings. No contribution to the flux of secondary neutrons was found from these.

This modification of the experimental arrangement decreased the contribution of secondary low-energy neutrons from surrounding material by about 40 %. In order to further decrease the correction for the influence of secondary neutrons, it was also found important to minimize the geometry of the samples.

A linear extrapolation of the measured dependences of the apparent activation cross section to zero distance and to zero thickness and diameter would give an incorrect cross-section value because of coupling effects between observed dependences. A change of the diameter is in fact also a change of the effective distance (defined in paper II) between the target and the sample. The coupling effects are particularly important if the distance is of the same magnitude as the sample diameter. It appears that a plot of the distance dependence and that of the diameter as a function of the effective distance

are close to each other, which implies that most of the diameter dependence is an effect of distance. The model calculation, described in paper VI, also indicate a weak dependence on the sample diameter.

As a consequence of this observation, measurements were performed in which the solid angle subtended by the sample was kept constant. Samples of different diameters were used. These results contain both the distance and the diameter dependences on the apparent cross section.

Extrapolation to zero effective distance gives a cross section value corrected for both distance and diameter. This value has to be corrected for the contribution from the sample thickness used.

A calculation method to estimate the effect of secondary neutrons produced and captured in the sample is described in paper VI. The energy distribution of secondary neutrons can fairly well be described by the preequilibrium and the statistical models.

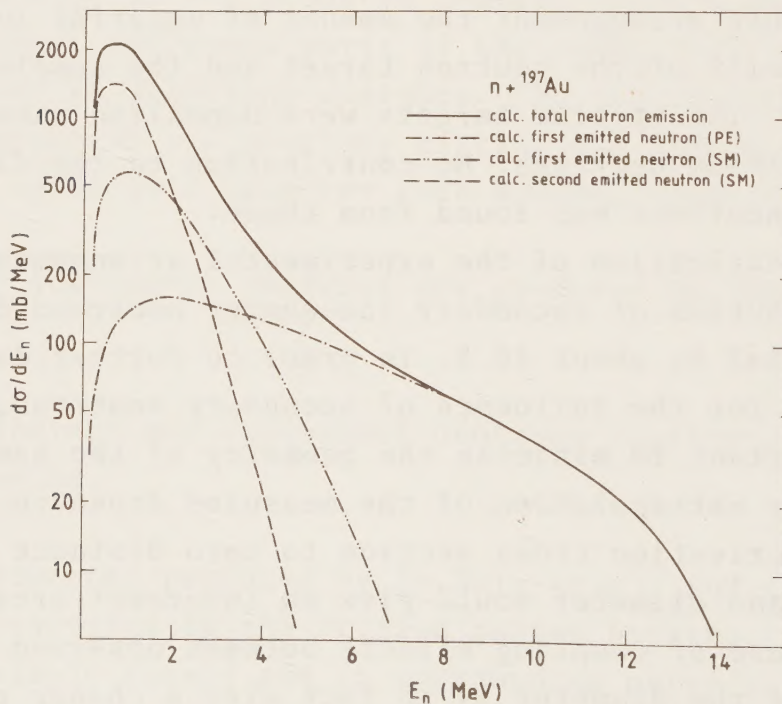


Fig.2 Cross section $d\sigma/dE_n$ for secondary neutrons from the interaction of 14.7 MeV neutrons with ^{197}Au . E_n is the energy in the neutron exit channel. (PE= preequilibrium model and SM= statistical model).

The preequilibrium model handles the neutron emission of the composite nucleus during its way to equilibrium. After reaching this, the emission is described by the statistical model. A calculated spectrum of secondary neutrons from the reaction $n + {}^{197}\text{Au}$ is displayed in Fig. 2. .

The contribution of primary neutrons as well as secondary neutrons to the apparent activation cross section is shown in Fig. 3. The calculation was made for the neutron capture reaction in ${}^{197}\text{Au}$ and for a specific sample (diameter: 5 mm and thickness: 0.3 mm). In this case the contribution of primary neutron capture is 1.09 mb and that for the secondary neutrons 0.97 mb. The figure also indicates that secondary neutrons above about 2 MeV do not contribute to the activation yield.

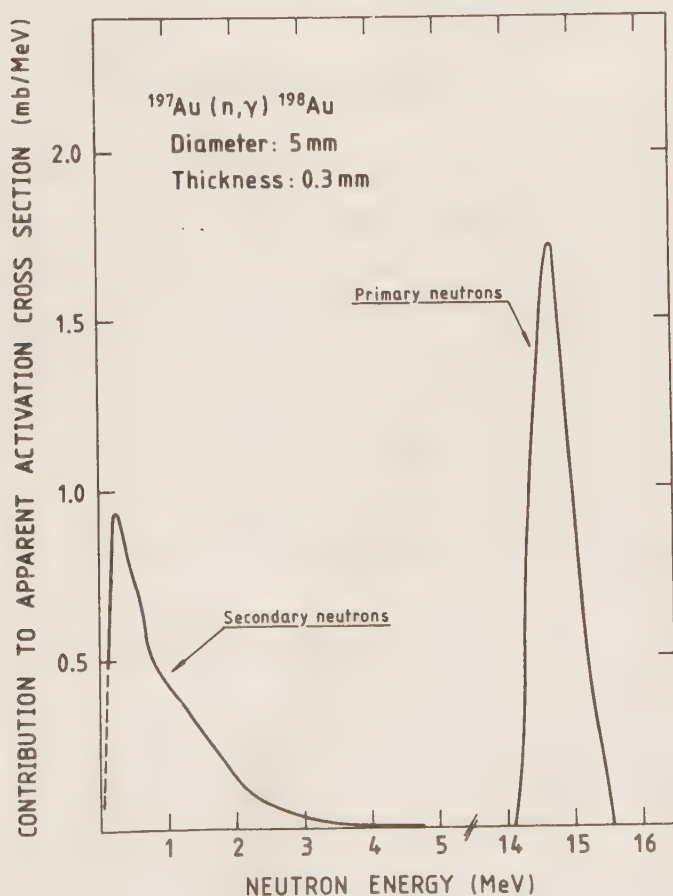


Fig.3 The contribution of primary and secondary neutrons to the apparent activation cross section in the reaction ${}^{197}\text{Au}(n,\gamma){}^{198}\text{Au}$.

For accurate measurements, the contribution of secondary neutrons should be minimized by using small, thin samples, small target sample distances, together with target backings of thin aluminium. It is also of importance to have a well-defined geometry and a small beam spot. However, results of high accuracy can, in some cases, be rather difficult to obtain because of these small samples, low neutron fluxes, and low cross sections.

The results reported in this dissertation show that 14 - 15 MeV neutron capture cross sections as measured with the activation technique are consistent with those measured by integrated γ -ray spectra, if proper corrections for lower energy neutrons are applied.

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